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CORROSION OF ALLOYS IN HYDROSPACE - 189 DAYS AT 5,900 FEET

By

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CORROSION OF ALLOYS IN HYDROSPACE - 189 DAYS AT 5,900 FEET

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ABSTRACT

A total of 525 specimens of 60 different alloys were exposed at a depth of 5,900 feet in the Pacific Ocean for 189 days in order to determine the effects of the deep ocean environments on their corrosion resistance.

Corrosion rates, types of corrosion, pit depths, and stress corrosion cracking resistance are presented.

The materials evaluated were aluminum alloys 5086-H34, H32 and H112 and 6061-T6, and welded and unwelded 5083-H113 and 7039-T64; welded nickel alloys Ni-Cu 400 and K-500, Ni-Cr-Fe 600 and 718, Ni-Cr-Mo 625, and Ni-Fe-Cr 825; and wire ropes Ni-Cr-Mo 625, Ni-Co-Cr-Mo, Ni-Mo-Cr "C" and Ni-Cr-Mo-103; three high strength-low alloy steels; six high strength steels; two austenitic cast irons; three stainless steels; two precipitation hardening stainless steels; and stainless steel and modified stainless steel wire ropes; and seven welded titanium alloys.

PREFACE

Since 1959 the Naval Civil Engineering Laboratory has been developing the technology necessary for designing, constructing, inspecting and maintaining structures and fixed equipment on the ocean floor. A part of this program is to determine the effects of deep ocean environments on the corrosion of metals and alloys.

A Submersible Test Unit (STU) was designed to which many test specimens can be attached. The STU can be lowered to the ocean floor for long periods of exposure, then retrieved.

Thus far, two deep ocean test sites in the Pacific Ocean have been selected. Eight STUs have been exposed and seven have been recovered. Test Site I (nominal depth of 6,000 feet) is approximately 81 nautical miles west-southwest of Port Hueneme, California, latitude 33°44'N and longitude 120°45'W. Test Site II (nominal depth of 2,500 feet) is 75 nautical miles west of Port Hueneme, California, latitude 34°06'N and longitude 120°42'W. In addition, a surface seawater exposure site (V) was established at Point Mugu, California, latitude 34°06'N and longitude 119°07'W to obtain surface immersion data for comparison purposes.

This report presents the results of the evaluations of 60 different alloys, many of which are newly developed alloys, after 189 days of exposure at a depth of 5,900 feet.

INTRODUCTION

The development of deep diving vehicles which can stay submerged for long periods of time has focused attention on the deep ocean as an operating environment. This has created a need for information concerning the behavior of common materials of construction as well as newly developed materials with promising potentials at depths as well as at the surface in seawater.

Since 1959 the Naval Civil Engineering Laboratory has been developing the technology necessary for designing, constructing, inspecting and maintaining structures and fixed equipment on the ocean floor. A part of this program is to determine the effects of deep ocean environments on the corrosion of metals and alloys.

In order to determine the effects of deep ocean environments on the corrosion of metals and alloys, a Submersible Test Unit (STU) was designed to which many test specimens can be attached. A STU unit is shown in the inset of Figure 1.

The test sites for the deep ocean exposures are shown in Figure 1 and their specific geographical locations are given in Table 1. The complete oceanographic data at these sites, obtained from NCEL cruises between 1961 and 1967, are summarized in Figure 2. Initially it was decided to utilize the site at the 6,000-foot depth (STU I-1, 2, 3 and 4). Because of the minimum oxygen concentration zone found between the 2,000- and 3,000-foot depths during the early oceanographic cruises, it was decided to establish a second site (STU II-1 and 2) at a nominal depth of 2,500 feet. For comparative purposes the surface seawater Site V was established. Even though the actual depths are shown in the tables, the nominal depths of 6,000 and 2,500 feet are used throughout the text.

A summary of the characteristics of the seawater 10 feet above the bottom sediments at the two deep ocean exposure sites and 5 feet below the surface at the surface exposure site is given in Table 1.

Sources of information pertaining to the biological characteristics of the bottom sediments, biological deterioration of materials, detailed oceanographic data, and construction, emplacement and retrieval of STU structures are given in Reference 1. Bottom sediments, as used herein, means the water-mud interface to a mud depth of about 6 inches.

The procedure for the preparation of the specimens for exposure and for evaluating them after exposure are described in Reference 2.

Previous reports pertaining to the performance of materials in the surface and deep ocean environments are given in References 1 through 12.

This report presents a discussion of the results of the corrosion of aluminum and nickel alloys, steels, stainless steels, and titanium alloys after 189 days of exposure at a depth of 5,900 feet, STU I-5, Table 1.

RESULTS AND DISCUSSIONS

Aluminum Alloys

The chemical compositions of the aluminum alloys are given in Table 2 and their corrosion rates and types of corrosion in Table 3.

Since the aluminum alloys corroded chiefly by pitting and crevice corrosion, the corrosion rates calculated from weight losses in Table 3 are meaningless. A good illustration of this is 6061-T6 where the calculated corrosion rates are 0.1 MPY in both the water and the bottom sediments, but the maximum and average pit depths are more than 10 times greater in the bottom sediments than in seawater, and crevice corrosion was very evident in the bottom sediments contrasted to none in the seawater.

For most aluminum alloys pitting and crevice corrosion were more severe in the bottom sediments than in the seawater. Also, pitting and crevice corrosion were more severe at depths than at the surface for the same period of exposure as is shown by comparing the data in Table 3 of Reference 11 with Table 3 of this report.

Pitting corrosion was more localized in the heat affected zones adjacent to the weld beads in alloys 5083-H113 and 7039-T64 than in the plate materials unaffected by the heat of welding.

Nickel Alloys

The chemical compositions of the nickel alloys are given in Table 4 and their corrosion rates and types of corrosion in Table 5.

In general, the corrosion rates of the nickel alloys in seawater and in the bottom sediments were comparable. There was pitting corrosion only in the Ni-Cu alloys 400 and K-500 -- that in the K-500 alloy being much more severe than that in the 400 alloy. There was crevice corrosion in three alloys, Ni-Cu alloys 400 and K500, and in Ni-Cr-Fe 600 alloy. Crevice corrosion was most severe in the Ni-Cr-Fe 600 alloy. There was no significant corrosion of the other three alloys, Ni-Cr-Fe 718, Ni-Cr-Mo 625 and Ni-Fe-Cr 825. There was incipient pitting or etching of the weld beads on Ni-Cu 400, Ni-Cr-Fe 718 and Ni-Fe-Cr 825 alloys.

Comparison of the corrosion performance of the alloys in Table 5 with companion alloys in Table 9 of Reference 11 shows that: (1) The performance of Ni-Cr-Fe 718 and Ni-Cr-Mo 625 alloys were the same; (2) crevice corrosion occurred in Ni-Fe-Cr 825 alloy at the surface in

contrast to none at depth; (3) corrosion rates, pitting and crevice corrosion of alloys Ni-Cu 400, Ni-Cu K-500 and Ni-Cr-Fe 600 were greater at the surface than at a depth of 6,000 feet after 6 months of exposure.

Steels, Cast Irons and Stainless Steels

The chemical compositions of the steels, cast irons and stainless steels are given in Table 6, and their corrosion rates and types of corrosion in Table 7.

The corrosion of the high strength steels (HS) and the 18 Ni maraging steel was uniform except for pitting in the circular weld beads of HS numbers 1 and 4 and crevice corrosion of the 18 Ni maraging steel. In all cases the corrosion rates were greater in the seawater than in the bottom sediments.

The pits in the weld bead of HS #4 were not typical of corrosion pits in steels. Their sides were nearly parallel and normal to the plane of the plate and were larger in diameter underneath the surface. A transverse section was cut through the weld bead to examine these voids in more detail. A section through the weld after polishing and etching is shown in Figure 3. The clean, smooth walls of the cavities and those which had no access to the surface indicate that they were due to entrapment of gas during the welding operation.

The corrosion rates of two of these steels (HS #1 and 18 Ni maraging, the only ones available for comparison) were considerably higher during exposure in surface seawater for the same period of exposure than at depth, as can be seen by comparing the data in Table 12, Reference 11, with that in Table 7.

The two austenitic cast irons corroded uniformly and at slower rates in the bottom sediments than in the seawater approximately 4 feet above the water-sediment interface. Their corrosion rates at depth were less than those at the surface for equivalent periods of exposure, Table 15, Reference 11.

Specimens of AISI Type 316 stainless steel tubing with fittings on each end and with a zinc anode attached to the end of one specimen were exposed in the seawater. There were rust stains and incipient crevice corrosion at the junctures of the tubes with the fittings, and at the junctures of the end caps with the nuts on the specimens without zinc anodes. There was no observable corrosion on the specimen to which the zinc anode was attached, indicating that the anode had prevented the inception of corrosion. The zinc anode was about 25 percent consumed.

The 20Cb-3 stainless steel was attacked by incipient crevice and pitting corrosion in the seawater and by severe crevice corrosion to a maximum depth of 40 mils in the bottom sediment. This alloy was attacked by incipient crevice corrosion during 6 months of exposure in surface seawater.

The aluminum coating on steel (coating weight 1 oz/ft^2, 2 mils thick on each side) was about 50 percent gone with bare steel exposed in some areas.

The zinc coating on steel (coating weight 1 oz/ft^2, 0.84 mils thick on each side) was completely gone and the steel was rusted. The corrosion rate of the zinc coated steel in the bottom sediments was about the same as the average for the bare steel specimens, indicating that the protection afforded by the zinc was of short duration. The corrosion rate of the zinc coated steel in seawater was 76 percent of the average for the bare steel specimens, indicating that the zinc coating had protected the steel for a longer period of time in the seawater than in the bottom sediment. In other words, the zinc had protected the steel for about 6 weeks of the total 27 weeks of exposure.

Comparing the two, the aluminum coating will protect steel for a considerably longer period of time at depth in seawater and in the bottom sediments than will an equivalent weight of zinc coating.

Two precipitation hardening stainless steels (362 and 455) in two precipitation hardened conditions (H950 and H1050), unwelded and welded, were painted with different paint coatings as given in Table 8. The bare 362 and 455 in both the H950 and H1050 heat treated conditions, unwelded and welded, were attacked by scattered pinpoint pitting and incipient crevice corrosion with selective attack in the form of deep pits in the weld bead of steel 362 in the H1050 condition. There was some flaking of Paint No. 1 (Table 8) and rust stains penetrated through the paint coating in some areas on both 362 and 455 alloys. There were no failures of paint coatings numbers 2, 6 and 7.

High strength-low alloy steels numbers 4, 5 and 13 were painted with paint coatings numbers 1, 4 and 5. The performance of paint coating number 1 on high strength-low alloy steels numbers 4, 5 and 13 was about the same as on alloys 362 and 455 in that rust stains had penetrated the paint coatings in some areas. Paint coating number 5 on the high strength-low alloy steels did not fail. Paint coating number 4 did not fail on high strength-low alloy steels numbers 5 and 13, but there was incipient paint failures and rust stains through the coating on high strength-low alloy steel number 4.

Titanium Alloys

The chemical compositions of the titanium alloys are given in Table 9 and their corrosion rates and types of corrosion in Table 10.

There was no visible corrosion on any of the alloys except the 13V-11Cr-3Al alloy partially embedded in the bottom sediments which failed by stress corrosion cracking. The stress corrosion cracks were normal to the weld beads and extended radially across the weld beads. Some of the cracks branched after they crossed the weld beads and propagated parallel to the weld beads.

Stress Corrosion

A number of the alloys were stressed in tension at stresses equivalent to 50 or 75 percent of their respective yield strengths to determine their susceptibility to stress corrosion cracking. These alloys, the levels of stress, and their susceptibility to stress corrosion cracking, both in the seawater and when partially embedded in the bottom sediments, are given in Table 11.

Only the 18 percent Ni maraging steel failed by stress corrosion cracking at 75 percent of its yield strength in seawater and at both 50 and 75 percent of its yield strength when partially embedded in the bottom sediments.

The other alloys, two aluminum alloys, a high strength-low alloy steel, two high strength steels, two precipitation hardening steels, and seven titanium alloys were immune to stress corrosion cracking in these environments for 189 days of exposure at a depth of 5,900 feet.

Wire Ropes

A number of wire ropes of different compositions were exposed. These wire ropes and their corrosion behavior are given in Table 12.

The zinc coating on the 0.250-inch diameter wire rope was completely gone with heavy rust in some grooves while the same weight of zinc coating (0.5 oz per sq ft) on the 0.500-inch diameter, same construction (3 x 19), was not completely gone and there was more zinc remaining on the 0.500-inch diameter, 3 x 7 construction wire rope. The reason for some zinc remaining on the 0.500-inch diameter ropes is that there is less surface area of steel for the zinc to protect than on the 0.250-inch diameter rope.

The polyurethane and polyethylene sheaths protected the zinc coated wires to a considerable extent. The sheaths were not punctured or broken, but seawater had penetrated to the metal ropes through the end terminations. That water had penetrated to the interface between the sheath and the rope was proven by puncturing the sheath, at which time seawater spurted out under considerable pressure. When a terminal on one end of each specimen was removed, the zinc coatings on the portions of the ropes which were inside the terminals were gone and the wires were rusted, chiefly on the ends of the ropes. The polyethylene sheath on one specimen had been punctured in many places prior to exposure. After exposure these holes were filled with white corrosion products, but there was no rust on the rope except inside the terminals on the ends.

Type 304 stainless steel wire ropes, whether or not they were stress relieved, corroded by pitting, tunneling and crevice corrosion which were more severe on internal wires. There were no broken wires in one 3 x 7 construction rope, but many broken wires on the 3 x 19 construction ropes. The addition of vanadium and nitrogen to the Type

304 composition did not improve its corrosion resistance. However, the addition of silicon resulted in some increase in corrosion resistance; the addition of copper and molybdenum resulted in considerable increase in corrosion resistance; and the addition of nitrogen, silicon and molybdenum resulted in a wire rope which was uncorroded.

Wire ropes fabricated from Ni-Cr-Mo 103, Ni-Cr-Mo 625, Ni-Mo-Cr "C", Ni-Co-Cr-Mo and Co-Cr-Ni-Fe-Mo were completely immune to corrosion. The Co-Cr-Ni-Fe-Mo rope was also immune from corrosion when stressed at 1,600 pounds (40 percent of its breaking load).

The fiberglass, monofilament wires, varying in diameter from 0.031- to 0.123-inch, became dull and brittle during exposure in the seawater.

SUMMARY

The purpose of this investigation was to determine the corrosion behavior of some alloys and the effects of welding on the corrosion of some alloys which had not been included in the earlier deep sea exposures. To accomplish this, 525 specimens of 60 different alloys were exposed at a depth of 5,900 feet in the Pacific Ocean for 189 days.

Aluminum Alloys

As with previous exposures of other aluminum alloys, pitting and crevice corrosion were more severe in the bottom sediments than in the seawater and were more severe at depth than at the surface for the same period of exposure. Welding of 5083-H113 and 7039-T64 caused some localized pitting in the heat affected zones adjacent to the weld beads.

Nickel Alloys

There was no corrosion of Ni-Cr-Mo 625 alloy in either seawater or in the bottom sediments, both unwelded and welded. There was no significant corrosion of alloys Ni-Cr-Fe 718 and Ni-Fe-Cr 825 except for incipient pitting or etching of the weld beads. Ni-Cr-Fe 600 alloy was attacked by crevice corrosion while alloys Ni-Cu 400 and Ni-Cu K-500 were attacked by both pitting and crevice corrosion, they being more severe on the Ni-Cu K-500 alloy.

The corrosion behavior of alloys Ni-Cr-Fe 718 and Ni-Cr-Mo 625 was the same at depth as at the surface. Corrosion of alloys Ni-Cu 400, Ni-Cu K-500, Ni-Cr-Fe 600 was greater at the surface than at depth. Alloy Ni-Fe-Cr 825 was attacked by crevice corrosion at the surface but was immune at depth.

Steels, Cast Irons and Stainless Steels

The steels, in general, corroded uniformly at depth as did the steels in previous exposures. However, there was some pitting in the weld beads of HS numbers 1 and 4 steels.

The austenitic cast irons also corroded uniformly, similar to the steels.

There was incipient crevice corrosion of AISI Type 316 stainless steel tubing at the junctions with the fittings. Zinc anodes prevented this type of corrosion.

Stainless steel 20Cb-3 was attacked by severe crevice corrosion in the bottom sediment and by incipient crevice and pitting corrosion in seawater.

An aluminum coating (1 oz/ft^2) on steel was about 50 percent consumed while the zinc coating (1 oz/ft^2) was completely consumed and the steel was rusting, indicating that an aluminum coating will provide longer protection to steel than will a zinc coating of the same weight (1 oz/ft^2).

The two precipitation hardened stainless steels, heat treated, unwelded and welded, were attacked by pinpoint pitting and incipient crevice corrosion except for deep pits localized in the weld bead of steel 362 in the H1050 condition. Paint coatings offered good protection except for a zinc rich primer alone.

Paint coatings 4 and 5, Table 8, protected three high strength-low alloy steels while the zinc rich primer alone permitted penetration of seawater and subsequent rusting.

Titanium Alloys

The titanium alloys, like previously exposed alloys, did not corrode except for stress corrosion cracking of titanium alloy 13V-11Cr-3Al, which had been welded with a 3-inch diameter circular weld bead and not subsequently stress relief annealed.

Stress Corrosion

An 18 percent Ni maraging steel was susceptible to stress corrosion cracking when stressed at 50 and 75 percent of its yield strength. Two aluminum alloys, a high strength-low alloy steel, two high strength steels, two precipitation hardening stainless steels and seven titanium alloys were immune to stress corrosion cracking.

Wire Ropes

A 0.5 oz/ft^2 zinc coating protected steel wire rope for approximately 6 months.

Polyurethane and polyethylene sheaths provided good protection to zinc coated wire rope except at the terminals which leaked, permitting seawater to penetrate between the sheathing and the rope.

AISI Type 304 stainless steel wire ropes, unrelieved and stress relieved, were severely attacked by pitting, tunneling and crevice

corrosion, resulting in many broken wires. The addition of vanadium and nitrogen to the basic Type 304 composition did not improve the corrosion resistance. The addition of other elements or combinations of elements to the basic Type 304 composition did result in increases in corrosion resistance of varying degrees, the most improvement being immunity to corrosion by the addition of molybdenum, silicon and nitrogen.

Wire ropes completely immune to corrosion were Ni-Cr-Mo 103, Ni-Cr-Mo 625, Ni-Mo-Cr "C", Ni-Co-Cr-Mo and Co-Cr-Ni-Fe-Mo.

Fiberglass monofilament wires became dull and brittle during exposure.

CONCLUSIONS

For a reasonable service life at depth in seawater, three years or less, aluminum alloys must be well protected because of their susceptibility to pitting and crevice corrosion. If protective maintenance cannot be performed, aluminum alloys should not be used for deep ocean applications.

Nickel base alloy Ni-Cr-Mo 625, unwelded and welded, can be used in seawater applications, unprotected, for many years of maintenance-free service where its mechanical and physical properties fulfill other requirements. The Ni-Cu alloys would not be recommended for use in seawater at depths because they pit and are susceptible to crevice corrosion in stagnant seawater -- also Ni-Cr-Fe 600 alloy because it is susceptible to crevice corrosion. Because of their tendency to pit, especially in the welded condition, Ni-Cr-Fe 718 and Ni-Fe-Cr 825 alloys can be recommended only for limited service in seawater.

Steels and cast irons, because of their uniform corrosion, can be recommended for seawater applications, especially when adequately protected.

A 1 oz/ft^2 aluminum coating will protect steel for a longer period of time than will a 1 oz/ft^2 zinc coating.

Stainless steels AISI Type 316 and 20Cb-3 alloy, because of their susceptibility to crevice corrosion and pitting corrosion, would not be recommended for deep sea applications except under special and unusual circumstances.

Two precipitation hardening stainless steels, 362 and 455, also must be protected for short duration deep sea applications. Paint coatings containing zinc rich primers and epoxy topcoats provided good protection for 6 months.

Titanium alloys, except for 13V-11Cr-3Al, are recommended for seawater applications in the unprotected condition.

An 18 percent Ni maraging steel, heat treated to a yield strength of 300,000 psi, would not be recommended for seawater applications because of its susceptibility to stress corrosion cracking at stresses equivalent to 50 percent of its yield strength and above.

A 0.5 oz/ft^2 zinc coating will protect steel wire rope for about 6 months in seawater.

Polyurethane and polyethylene sheaths protect steel wire ropes, but improvements must be made in the terminations to prevent seawater intrusion.

AISI Type 304 stainless steel wire rope would not be recommended for seawater applications.

Wire ropes fabricated of alloys Ni-Cr-Mo 103, Ni-Cr-Mo 625, Ni-Mo-Cr "C", Ni-Co-Cr-Mo and Co-Cr-Ni-Fe-Mo would be recommended for trouble-free seawater applications where the cost can be justified.

Fiberglass monofilament wires would not be recommended for seawater applications because of their embrittlement.

Table 1. Exposure Site Locations and Seawater Characteristics

Site No.	Latitude N	Longitude W	Depth, Feet	Exposure, Days	Temp. °C	Oxygen ml/1 (1)	Salinity ppt (2)	Ph	Current, Knots, Avg.
I-1	33°46'	120°37'	5300	1064	2.6	1.2	34.51	7.5	0.03
I-2	33°44'	120°45'	5640	751	2.3	1.3	34.51	7.6	0.03
I-3	33°44'	120°45'	5640	123	2.3	1.3	34.51	7.6	0.03
I-4	33°46'	120°46'	6780	403	2.2	1.6	34.40	7.7	0.03
I-5	33°51'	120°35'	5900	189	2.3	1.6	34.6	7.4	0.03
II-1	34°06'	120°42'	2340	197	5.0	0.4	34.36	7.5	0.06
II-2	34°06'	120°42'	2370	402	5.0	0.4	34.36	7.5	0.06
V	34°06'	119°07'	5	181	12-19	3.9-6.6	33.51	8.1	Variable

(1) ml/1 - milliliters per liter

(2) ppt - parts per thousand

Table 2. Chemical Compositions of Aluminum Alloys, Percent by Weight

Alloy	Gauge (in.)	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al(1)
5083-H113	0.500	0.40	0.40	0.10	0.65	4.5	0.15	0.25	0.15	R
5086-H34	0.125	0.40	0.50	0.10	0.45	4.0	0.15	0.25	0.15	R
5086-H32	0.500	0.15	0.25	0.05	0.32	3.75	0.12	0.12	0.01	R
5086-H112	(2)	--	--	--	0.45	4.0	0.15	--	--	R
6061-T6	0.125	0.60	0.70	0.27	0.15	1.0	0.25	0.25	0.15	R
7039-T64	0.500	0.30	0.40	0.10	0.25	2.8	0.20	4.0	0.10	R

(1) R = remainder

(2) 3" x 3" x 1/2" angle

Table 3. Corrosion of Aluminum Alloys in Seawater, 189 Days at 5900 Feet.

Alloy	Location	Corrosion Rate, MPY (1)(14)	Pit Depth, Mils		Crevice Corrosion Depth, Mils	Corrosion Type (2)
			Max	Avg		
5083-H113	Water	0.1	I	-	30.0	C, IP
"	Sediment	0.3	20.0	9.5	11.0	P, C
5083-H113 (3)	Water	0.1	4.0	2.1	0	SLP
"	Sediment	0.2	4.0	2.1	I	IC, SEP (4)
5086-H34	Water	0.2	3.0	1.6	0	SLP
"	Sediment	0.7	6.0	3.2	126(PR)	E, P, C (5)
5086-H32	Water	0.1	33.0	19.2	15.0	C, SCP
"	Sediment	0.2	23.0	16.7	4.0	C, SCP
5086-H112	Sediment	0.1	21.0	12.5	32.0	C, SCP
6061-T6	Water	0.1	3.0	1.4	0	SCP
"	Sediment	0.1	33.0	19.1	18.0	C, SCP (6)
7039-T64	Water	0.2	I	-	14.0	C, IP
"	Sediment	0.3	40.0	24.0	45.0	C, SCP
7039-T64 (7)	Water	0.3	41.0	24.2	I	IC, P(HAZ) (8)
"	Sediment	0.3	47.0	22.7	I	IC, P (9)
6061-T6 (10)	Water	-	-	-	-	PF, WCP, P
6061-T6	Water	-	-	-	-	NPF
7075-T73 (10)	Water	-	-	-	-	PBCP, WCP, P
7075-T73 (11)	Water	-	-	-	-	PP, PF
7075-T73 (12)	Water	-	-	-	-	(13)

Table 3. (Cont'd)

(1) MPY - Mils penetration per year calculated from weight loss

(2) Symbols for types of corrosion:

C - Crevice	PP - Pinpoint pits
E - Edge	PR - Perforated
HAZ - Heat affected zone	PBCP - Paint blistered, crazed and peeled
I - Incipient	SC - Scattered
NPF - No paint failure	SL - Slight
P - Pitting	WCP - White corrosion products
PF - Paint failure	

(3) Transverse butt weld, 5183 wire, MIG process.

(4) Scattered pitting, heavier in sediment than in water, shallow interconnected pitting in heat affected zone parallel to weld bead.

(5) One pit 46 m; one pit in edge 55 m.

(6) Interconnected pits in portion in sediment

(7) Transverse butt weld, 7039 wire, MIG process.

(8) Broad interconnected pits in heat affected zone (HAZ)

(9) Broad pits also in HAZ.

(10) Paint #1 - zinc rich primer, 8 mils

(11) Topcoat of white paint peeled to metal and wrinkled when received.

(12) Longitudinal butt weld, galvalum anode.

(13) Anode 1/8 gone, white corrosion products with pits underneath in heat affected zone.

(14) These corrosion rates are meaningless for design purposes since the aluminum alloys corroded chiefly by the pitting and crevice types of corrosion. See columns 4, 5 and 6.

Table 4. Chemical Composition of Nickel Alloys, Percent by Weight

Alloy	Ni	C	Mn	Fe	S	Si	Cu	Cr	Ti	Mo	Other
Ni-Cu 400	65.17	0.11	1.06	0.90	0.007	0.10	32.62	--	--	--	--
Ni-Cu K-500	65.00	0.15	0.60	1.00	0.005	0.15	29.50	--	0.50	--	Al 2.80
Ni-Cr-Fe 600	76.00	0.04	0.20	7.20	0.007	0.20	0.10	15.8	--	--	--
Ni-Cr-Fe 718	53.70	0.03	0.06	16.93	0.007	0.17	0.06	19.16	0.99	3.00	Cb 5.24 Ta 0.07 Co 0.05 Al 0.51
N-Cr-Mo 625(3)	62.02	0.01	0.01	2.60	0.101	0.17	0.02	21.81	0.27	9.39	Al 0.19 Cb+Ta 3.48
Ni-Fe-Cr 825	42.35	0.03	0.84	30.29	0.007	0.25	1.81	20.44	0.82	3.09	Al 0.05
Ni-Co-Cr-Mo(1)	35.0	--	--	--	--	--	--	20.0	--	10.0	Co 35.0
Ni-Mo-Cr "C"(2)	60.2	0.014	0.45	5.56	0.008	0.53	--	15.9	--	15.0	W 3.14
Ni-Cr-Mo 103(2)	67.0	0.02	--	--	--	--	--	18.0	--	14.0	Cb 0.5
Co-Cr-Ni-Fe-Mo(2)	14.96	0.05	1.96	14.60	--	0.74	--	19.84	--	7.14	Al 0.058 Co 40.46 Be 0.07

(1) Wire rope and bolts

(2) Wire rope

(3) Sheet and wire rope

Table 5. Corrosion of Nickel Alloys in Seawater, 189 Days at 5900 Feet

Alloy	Location	Corrosion Rate, MPY (1)	Pit Depth, Mils		Crevice Corrosion, Depth, Mils	Corrosion Type (2)
			Max	Avg		
Ni-Cu 400	Water	0.4	I	-	5.0	C, IP
Ni-Cu 400	Sediment	0.3	1.0	1.0	I	IC, IP
Ni-Cu 400 (3)	Water	0.4	I		0	IP (4)
Ni-Cu 400 (3)	Sediment	0.4	I		0	IP (4)
Ni-Cu 400 (5)	Water	0.3	0	0	0	U
Ni-Cu 400 (5)	Sediment	0.3	0	0	0	U
Ni-Cu K-500	Water	0.1	9.0	6.3	16.0	C, SCP
Ni-Cu K-500	Sediment	0.2	11.0	6.9	26.0	C, SCP
Ni-Cr-Fe 600	Water	<0.1	0	0	39.0	C
Ni-Cr-Fe 600	Sediment	0.0	0	0	I	IC
Ni-Cr-Fe 718	Water	0.0	0	0	0	NC
Ni-Cr-Fe 718	Sediment	<0.1	0	0	0	NC
Ni-Cr-Fe 718 (6)	Water	<0.1	0	0	0	NC
Ni-Cr-Fe 718 (6)	Sediment	<0.1	0	0	0	NC
Ni-Cr-Fe 718 (7)	Water	<0.1	0	0	0	ET (8)
Ni-Cr-Fe 718 (7)	Sediment	<0.1	0	0	0	ET (8)
Ni-Cr-Mo 625	Water	0.0	0	0	0	NC
Ni-Cr-Mo 625	Sediment	0.0	0	0	0	NC
Ni-Cr-Mo 625 (9)	Water	0.0	0	0	0	NC
Ni-Cr-Mo 625 (9)	Sediment	0.0	0	0	0	NC
Ni-Cr-Mo 625 (10)	Water	0.0	0	0	0	NC
Ni-Cr-Mo 625 (10)	Sediment	0.0	0	0	0	NC
Ni-Fe-Cr 825	Water	<0.1	0	0	0	NC
Ni-Fe-Cr 825	Sediment	<0.1	0	0	0	NC
Ni-Fe-Cr 825 (11)	Water	<0.1	I	-	0	IP (12)
Ni-Fe-Cr 825 (11)	Sediment	<0.1	0	0	0	NC
Ni-Fe-Cr 825 (13)	Water	0.0	0	0	0	NC
Ni-Fe-Cr 825 (13)	Sediment	<0.1	0	0	0	NC

Table 5. (Cont'd)

(1) MPY - Mils penetration per year calculated from weight loss

(2) Symbols for types of corrosion:

C - Crevice
ET - Etched
I - Incipient
NC - No visible corrosion
P - Pitting
U - Uniform
SC - Scattered

(3) Longitudinal butt weld, electrode 190

(4) Incipient pitting on weld bead

(5) Circular weld, 3" diameter, electrode 190

(6) Longitudinal butt weld, electrode 718

(7) Circular weld, 3" diameter, electrode 718

(8) Weld bead only

(9) Longitudinal butt weld, electrode 625

(10) Circular weld, 3" diameter, electrode 625

(11) Longitudinal butt weld, electrode 135

(12) Incipient pitting along weld bead only

(13) Circular weld, 3" diameter, electrode 135

Table 6. Chemical Composition of Steels, Percent by Weight

Alloy	C	Mn	P	S	Si	Ni	Cr	Mo	V	Co	Al	Other	Fe[1]
HS #1[2]	0.12	0.84	0.003	0.005	0.32	4.91	0.56	0.48	0.07	--	0.021	O 0.003 N 0.010	R
HS #3	0.24	0.19	0.004	0.010	0.01	8.36	0.47	0.47	0.06	3.90	--	--	R
HS #4	0.11	0.38	0.006	0.013	0.27	2.76	1.23	0.30	0.10	--	0.035	--	R
HS #5	0.11	0.06	0.005	0.005	0.067	9.91	2.20	0.98	--	8.00	0.003	O 0.001 N 0.002	R
HS #6	0.18	0.30	0.007	0.004	0.02	9.18	0.77	1.01	0.09	4.39	--	Cu 0.13	R
HSLA #4	--	0.36	0.08	--	0.41	0.32	0.72	--	--	--	--	Cu 0.38	R
HSLA #5	0.14	0.78	0.02	0.025	0.23	0.72	0.56	0.42	0.36	--	--	Cu 0.22 B 0.0041	R
HSLA #13	0.23	1.18	0.04	0.05	0.30	--	--	--	--	--	--	Cb+V 0.02	R
Plow steel	No composition limits											N 0.015	
18% Ni Maraging	0.02	0.10	0.005	0.007	0.14	17.92	--	4.78	--	8.75	0.17	Ti 0.94 B 0.003	R
Cast Iron, Type 4, Austenitic	2.13	0.79	--	--	5.60	29.98	5.02	--	--	--	--	Cu 0.16	R
Cast Iron, Type D-2c, Austenitic	2.45	2.12	--	--	2.38	22.34	0.08	--	--	--	--	--	R
AISI Type 304	0.06	1.73	0.024	0.013	0.43	10.0	18.8	--	--	--	--	--	R
AISI Type 316	0.06	1.61	0.021	0.016	0.40	13.6	18.3	2.41	--	--	--	--	R

Table 6. (Cont'd)

Alloy	C	Mn	P	S	Si	Ni	Cr	Mo	V	Co	Al	Other	Fe[1]
20Cb-3	--	--	--	--	--	34	20	2.3	--	--	--	Cu 3.4	R
399 Fe-Cr-Ni-Mo-Cu[3]	0.06	1.55	0.010	0.013	1.39	13.90	18.64	2.44	<0.02	--	--	Cu 1.95 N 0.06	R
400 Fe-Cr-Ni-Mo-Si-N[3]	0.07	1.60	0.013	0.015	2.28	13.80	18.70	2.47	<0.02	--	--	N 0.17	R
401 Fe-Cr-Ni-V-N[3]	0.07	1.35	0.012	0.014	0.98	13.70	19.56	<0.01	3.50	--	--	N 0.15	R
402 Fe-Cr-Ni-Si[3]	0.06	1.51	0.005	0.008	1.92	17.82	17.82	0.02	--	--	--	Cu 0.03	R
362	0.03	0.30	0.015	0.015	0.20	6.50	14.50	--	--	--	--	Ti 0.80	R
455	0.03	0.50	--	--	0.50	8.50	12.00	--	--	--	--	Ti 1.15 Cb+Ta 0.50 Cu 1.50	R

(1) R - remainder
(2) High strength steel
(3) Wire rope

Table 7. Corrosion of Steels in Seawater, 189 Days at 5,900 Feet

Alloy	Location	Corrosion Rate, MPY[1]	Corrosion Type[2]	Remarks
HS #1	Water	2.7	U	
"	Sediment	1.8	U	
HS #1[3]	Water	2.7	U	Weld bead same as plate
"	Sediment	1.8	U	Weld bead same as plate
HS #1[4]	Water	2.6	U	Weld bead same as plate
"	Sediment	1.6	U	1 pit in weld bead, 45 mils deep
HS #4	Water	2.9	U	
"	Sediment	1.8	U	
HS #4[3]	Water	2.3	U	Weld bead same as plate
"	Sediment	1.5	U	Weld bead same as plate
HS #4[4]	Water	2.5	U,P	Weld bead pitted, one side, 154 m (max), 73.4 m (avg 15 pits)
"	Sediment	1.7	U	Weld bead same as plate
HS #5	Water	2.3	U	
"	Sediment	1.9	U	
HS #5[3]	Water	2.0	U	Weld bead same as plate
"	Sediment	1.7	U	Weld bead same as plate
HS #5[4]	Water	1.8	U	Weld bead lighter gray than plate
"	Sediment	1.6	U	Weld bead lighter gray than plate
HS #6	Water	2.5	U	
"	Sediment	1.6	U	
HS #6[3]	Water	2.8	U	Weld bead same as plate
"	Sediment	1.5	U	Weld bead same as plate
HS #6[4]	Water	2.9	U	Weld bead same as plate
"	Sediment	2.7	U	Weld bead same as plate
18 Ni Maraging	Water	2.2	U	Crevice corrosion 3 m
" "	Sediment	1.7	U	

Table 7. (Cont'd)

Alloy	Location	Corrosion Rate, MPY(1)	Corrosion(2) Type	Remarks
Type 4 Austenitic Cast Iron	Water	2.0	U	
	Sediment	1.4	U	
Type D-2c Austenitic Cast Iron	Water	3.3	U	
	Sediment	1.5	U	
AISI Type 316 Tubing	Water	-	IC	There was incipient crevice corrosion at the edge of the couplings and on the threaded plugs
AISI Type 316 Tubing + Zn anode	Water	-	NC	There was no corrosion, especially crevice corrosion, because of the protection afforded by the Zn anode. The anode was 25% consumed.
20Cb-3	Water	<0.1	IC,IP	
	Sediment	<0.1	SC	Crevice corrosion, 40 m (max) under plastic nut
Al Coated Steel 1 oz/sq ft	Water	0.2	U	Al coating 50% gone, to bare steel in places
	Sediment	0.2	U	Al coating 55% gone, mottled, bare steel in places
Zn Coated Steel 1 oz/sq ft	Water	1.9	U	Zn coating completely gone
	Sediment	1.6	U	Zn coating completely gone
362, H950	Water	-	SPP,IC	
362, H950(4)	Water	-	SPP,IC	SPP in weld bead
362, H950(4)(5)	Water	-	SFP,RS	
362, H950(5)	Water	-	SFP,RS	

Table 7. (Cont'd)

Alloy	Location	Corrosion Rate, MPY(1)	Corrosion(2) Type	Remarks
362,H1050	Water	-	SPP,IC	
362, H1050(4)	Water	-	SPP,SC	Deep pits in weld bead
362, H1050(4)(5)	Water	-	SFP,RS	Rust stains on weld bead
362, H1050(5)	Water	-	SFP,RS	
455, H950	Water	-	SPP,IC	
455, H950(4)	Water	-	SPP,IC	Few pits in weld bead
455, H950(6)	Water	-	NPF	
455, H950(7)	Water	-	NPF	
455, H950(4)(6)	Water	-	NPF	
455, H1050	Water	-	SPP,IC	
455, H1050(4)	Water	-	SPP,IC	Few pits in weld bead
455, H1050(6)	Water	-	NPF	
455, H1050(8)	Water	-	NPF	
455, H1050(4)(6)	Water	-	NPF	
HSLA #4(5)	Water	-	RS	
HSLA #4(9)	Water	-	IPF,RS	
HSLA #4(10)	Water	-	NPF	
HSLA #5(5)	Water	-	RS	
HSLA #5(9)	Water	-	NPF	
HSLA #13(5)	Water	-	RS	
HSLA #13(9)	Water	-	NPF	

Table 7. (Cont'd)

(1) MPY - mils penetration per year calculated from weight loss
(2) Symbols for types of corrosion:

C - Crevice
I - Incipient
NC - No visible corrosion
NPF - No paint failure
P - Pitting
RS - Rust stains
S - Severe
SFP - Some flaked paint
SPP - Scattered pinpoint pits
U - Uniform corrosion

Numbers in Remarks column (154 m) signify depth of attack in mils

(3) Transverse butt weld
(4) Circular weld - 3" diameter circle in center of specimen
(5) Paint #1 - zinc rich primer, 8 mils
(6) Paint #2 - zinc rich primer (8 mils), wash primer MIL C-8514 (1 mil), epoxy topcoat (6 mils), total 15 mils
(7) Paint #7 - wash primer MIL-C-8514, epoxy primer, epoxy topcoat, 7 mils
(8) Paint #6 - wash primer MIL-C-8514, red lead epoxy primer, epoxy topcoat, 7 mils
(9) Paint #4 - Epoxy tar primer (8 mils), aluminum pigmented epoxy tar topcoat (8 mils), 16 mils
(10) Paint #5 - epoxy tar primer (8 mils), epoxy tar topcoat (8 mils), 16 mils

Table 8. Paint Coatings for Steels

Paint Coating No.	Thickness, mils	Type
1	8	Zinc rich primer
2	8 1 6	Zinc rich primer Wash primer, MIL-C-8514 Epoxy topcoat
4	8 8	Epoxy tar primer Epoxy tar topcoat, aluminum pigmented
5	8 8	Epoxy tar primer Epoxy tar topcoat
6	7	Wash primer, MIL-C-8514, red lead primer, epoxy topcoat
7	7	Wash primer, MIL-C-8514, epoxy primer, epoxy topcoat

Table 9. Chemical Composition of Titanium Alloys, Percent by Weight

Alloy	C	Fe	N	H	O	Al	V	Cr	Other	Ti(1)
75A	0.027	0.20	0.026	0.004	–	–	–	–	–	R
Ti-0.15Pd	0.022	0.06	0.010	0.004	0.15	–	–	–	Pd 0.14	R
5Al-2.5Sn	0.024	0.32	0.013	0.008	0.18	5.1	–	–	Sn 2.4	R
6Al-4V	0.023	0.12	0.014	0.007	0.11	5.9	4.0	–	–	R
13V-11Cr-3Al	0.021	0.14	0.027	0.010	0.12	3.0	13.6	10.9	–	R
7Al-2Cb-1Ta	0.023	0.06	0.006	0.002	0.07	7.0	–	–	Cb 2.0 Ta 1.0	R
6Al-2Cb-1Ta-1Mo	0.02	0.06	0.006	0.002	0.077	6.1	–	–	Cb 2.2 Ta 1.1 Mo 0.74	R

(1) R = Remainder

Table 10. Corrosion of Titanium Alloys in Seawater, 189 Days at 5,900 Feet

Alloy	Location	Corrosion Rate, MPY(1)	Corrosion Type(2)
75A(3)	Water	0.0	NC
75A(3)	Sediment	0.0	NC(5)
75A(4)	Water	0.0	NC
75A(4)	Sediment	0.0	NC(5)
0.15Pd(3)	Water	0.0	NC
0.15Pd(3)	Sediment	0.0	NC(5)
0.15Pd(4)	Water	0.0	NC
0.15Pd(4)	Sediment	0.0	NC(5)
5Al-2.5Sn(3)	Water	0.0	NC
5Al-2.5Sn(3)	Sediment	0.0	NC(5)
5Al-2.5Sn(4)	Water	0.0	NC
5Al-2.5Sn(4)	Sediment	0.0	NC(5)
6Al-4V(3)	Water	0.0	NC
6Al-4V(3)	Sediment	0.0	NC(5)
6Al-4V(4)	Water	0.0	NC
6Al-4V(4)	Sediment	0.0	NC(5)
13V-11Cr-3Al(3)	Water	0.0	NC
13V-11Cr-3Al(3)	Sediment	0.0	NC(5)
13V-11Cr-3Al(4)	Water	0.0	NC
13V-11Cr-3Al(4)	Sediment	0.0	SCC(6)
7Al-2Cb-1Ta(3)	Water	0.0	NC
7Al-2Cb-1Ta(3)	Sediment	0.0	NC(5)
7Al-2Cb-1Ta(4)	Water	0.0	NC
7Al-2Cb-1Ta(4)	Sediment	0.0	NC(5)

Table 10. (Cont'd)

Alloy	Location	Corrosion Rate, MPY(1)	Corrosion Type(2)
6Al-2Cb-1Ta-1Mo	Water	0.0	NC
6Al-2Cb-1Ta-1Mo	Sediment	0.0	NC(5)
6Al-2Cb-1Ta-1Mo(3)	Water	0.0	NC
6Al-2Cb-1Ta-1Mo(3)	Sediment	0.0	NC(5)
6Al-2Cb-1Ta-1Mo(4)	Water	0.0	NC
6Al-2Cb-1Ta-1Mo(4)	Sediment	0.0	NC(5)

(1) MPY - mils penetration per year calculated from weight loss.

(2) Symbols for types of corrosion:

NC - No visible corrosion
SCC - Stress corrosion cracks

(3) Transverse butt weld.

(4) Circular (3" dia.) weld in center of specimen.

(5) Bluish film on portion in sediment.

(6) Two cracks in each specimen perpendicular to and across weld beads, some branching, penetrate through 0.125" thick plate. Bluish film on portion in sediment.

Table 11. Stress Corrosion of Alloys in Seawater, 189 Days at 5,900 Feet

Alloy	Percent of Yield Strength	Stress, KSI	Water		Sediment	
			Number Exposed	Number Failed	Number Exposed	Number Failed
5083-H113	50	17.3	3	0	3	0
"	75	26.0	3	0	3	0
5083-H113(1)	50	15.5	3	0	3	0
"	75	23.2	3	0	3	0
7039-T64	50	26.6	3	0	3	0
"	75	40.0	3	0	3	0
7039-T64(2)	50	27.0	3	0	3	0
"	75	40.5	3	0	3	0
18% Ni Maraging	50	157.7	3	0	3	2
" "	75	236.5	3	3	3	3
HS #6	50	95.5	3	0	3	0
"	75	143.3	3	0	3	0
HS #6(3)	50	95.5	3	0	3	0
HS #6	75	143.3	3	0	3	0
HS #3	50	86.0	3	0	3	0
HS #3	75	128.9	3	0	3	0
Ti-75A(3)	50	41.2	3	0	3	0
"	75	61.7	3	0	3	0
Ti-0.15Pd(3)	50	24.7	3	0	3	0
"	75	37.1	3	0	3	0
Ti-5Al-2.5Sn(3)	50	61.8	3	0	3	0
" "	75	92.7	3	0	3	0
Ti-6Al-4V(3)	50	65.7	3	0	3	0
" "	75	98.6	3	0	3	0

Table 11. (Cont'd)

Alloy	Percent of Yield Strength	Stress, KSI	Water		Sediment	
			Number Exposed	Number Failed	Number Exposed	Number Failed
Ti-13V-11Cr-3Al(3)	50	63.0	3	0	3	0
" "	75	94.5	3	0	3	0
Ti-7Al-2Cb-1Ta(3)	50	49.9	3	0	3	0
" "	75	74.8	3	0	3	0
Ti-6Al-2Cb-1Ta-1Mo(3)	50	59.5	3	0	3	0
" "	75	89.3	3	0	3	0
362,H1050(4)(10)	75		5	0	-	-
362,H1050(5)	75		6	0	-	-
362,H1050(8)	75		1	0	-	-
362,H1050(9)	75		1	0	-	-
362,H950(4)(10)	75		3	0	-	-
362,H950(5)	75		6	0	-	-
455,H950(4)(11)	75		2	0	-	-
455,H1050(4)	75		1	0	-	-
455,H1050(5)	75		1	0	-	-
HSLA #5(5)	75		2	0	-	-
HSLA #5(6)	75		2	0	-	-
HSLA #5(7)	75		1	0	-	-
HSLA #4(5)	75		1	0	-	-
HSLA #4(6)	75		2	0	-	-
HSLA #4(7)	75		1	0	-	-
HSLA #13(5)(12)	75		2	0	-	-
HSLA #13(6)	75		2	0	-	-
HSLA #13(7)	75		1	0	-	-

Table 11. (Cont'd)

(1) MIG welded with 5183 wire
(2) MIG welded with 7039 wire
(3) TIG welded
(4) Unpainted
(5) Paint #1 - zinc rich primer, 8 mils
(6) Paint #2 - zinc rich primer, 8 mils + wash primer (MIL-C-8514), 1 mil + epoxy, 6 mils, total 15 mils
(7) Paint #5 - epoxy tar primer, 8 mils + epoxy tar topcoat, 8 mils, total 16 mils
(8) Paint #6 - wash primer (MIL-C-8514) + red lead epoxy primer + epoxy topcoat, 7 mils
(9) Paint #7 - wash primer (MIL-C-8514) + epoxy primer + epoxy topcoat, 7 mils
(10) Crevice corrosion at bolt head or bolt holes
(11) Rust spots in weld beads
(12) Rust stains on 50% of surface

Note: There were no paint failures except as noted in footnote 12

Table 12. Corrosion of Wire Ropes in Seawater, 189 Days at 5,900 Feet

Alloy	Location	Diameter, Inch	Construction	Coating	Remarks
Plow Steel[(1)(2)]	Water	0.250	3 x 19	Zn, 0.50 oz/ft^2	Light uniform rust, heavy in some grooves, zinc completely gone.
Plow Steel[(1)]	Water	0.500	3 x 19	Zn, 0.50 oz/ft^2	Yellow with few areas of heavy rust in grooves, some zinc remaining.
Plow Steel[(1)]	Water	0.500	3 x 7	Zn, 0.50 oz/ft^2	Gray-yellow, few areas of white corrosion products, few areas of yellow corrosion products in grooves, zinc not completely gone in many areas.
Plow Steel[(1)]	Water	0.500	3 x 19	Zn, 0.50 oz/ft^2, polyurethane, transparent	No breaks in coating, some white corrosion products on wires, otherwise gray in color, seawater escaped under pressure when polyurethane was punctured, terminals on ends leaked slightly.
Plow Steel[(1)]	Water	0.500	3 x 19	Zn, 0.50 oz/ft^2, polyethylene, black	No breaks in coating, seawater escaped under pressure when polyethylene was punctured, terminals on ends leaked, zinc gone near ends and wires rusted, white corrosion products on wires away from terminals.
Plow Steel[(1)]	Water	0.500	3 x 19	Zn, 0.50 oz/ft^2, polyethylene, black, punctured	No rust at punctures, some white corrosion products in holes, seawater escaped under pressure when polyethylene was punctured, terminals on ends leaked, zinc gone near ends and wires rusted, white corrosion products on wires away from ends.

Table 12. (Cont'd)

Alloy	Location	Diameter, Inch	Construction	Coating	Remarks
AISI Type 304 SS	Water	0.187	3 x 19	None	Cleaned - many broken wires, tunneling, pitting and crevice corrosion worse on internal wires.
AISI Type 304 SS(2)	Water	0.187	3 x 19	None	Cleaned - numerous broken wires, tunneling, pitting and crevice corrosion worse on internal wires.
AISI Type 304 SS	Water	0.187	3 x 7	None	Cleaned - some broken wires, pitting, tunneling and crevice corrosion worse on internal wires.
AISI Type 304 SS(2)	Water	0.187	3 x 7	None	Cleaned - no broken wires, pitting, tunneling and crevice corrosion worse on internal wires.
Fe-Cr-Ni-Si SS	Water	0.125	1 x 7	None	Cleaned - many shallow pits and many areas of slight crevice corrosion.
Fe-Cr-Ni-Mo-Cu SS	Water	0.125	1 x 7	None	Cleaned - Incipient crevice corrosion.
Fe-Cr-Ni-Mo-Si-N SS	Water	0.125	1 x 7	None	Cleaned - no visible corrosion.
Fe-Cr-Ni-V-N SS	Water	0.125	1 x 7	None	Only ends recovered, failed by crevice corrosion inside potting compound.
Ni-Cr-Mo 103	Water	0.250	7 x 19	None	No visible corrosion, original metallic sheen still present.
Ni-Cr-Mo 103	Sediment	0.250	7 x 19	None	Same as seawater exposure.
Ni-Cr-Mo 625	Water	0.250	7 x 19	None	No visible corrosion, original metallic sheen still present.

Table 12. (Cont'd)

Alloy	Location	Diameter, Inch	Construction	Coating	Remarks
Ni-Cr-Mo 625	Sediment	0.250	7 x 19	None	Same as seawater exposure.
Ni-Mo-Cr "C"	Water	0.062	1 x 7	None	No visible corrosion, original metallic sheen still present.
Ni-Co-Cr-Mo	Water	0.062	1 x 7	None	No visible corrosion, original metallic sheen still present.
Co-Cr-Ni-Fe-Mo	Water	0.187	3 x 19	None	No visible corrosion, original blue tarnish gone leaving bright metallic sheen.
Co-Cr-Ni-Fe-Mo	Water	0.187	3 x 19	None	Stressed at 1,600 lb (original breaking strength 3,980 lb) prior to exposure. After exposure, no failure, no visible corrosion, original blue tarnish gone leaving bright metallic sheen.
Fiberglass	Water	0.123	Monofilament	None	Original breaking strength, 3,000 lb - after exposure, dull and brittle.
Fiberglass	Water	0.094	Monofilament	None	Original breaking strength, 1,600 lb - after exposure, dull and brittle.
Fiberglass	Water	0.072	Monofilament	None	Original breaking strength, 1,100 lb - after exposure, dull and brittle.
Fiberglass	Water	0.046	Monofilament	None	Original breaking strength, 440 lb - after exposure, dull and brittle.
Fiberglass	Water	0.031	Monofilament	None	Original breaking strength, 220 lb - after exposure, dull and brittle.

(1) Extra improved plow steel, high strength
(2) Stress relieved

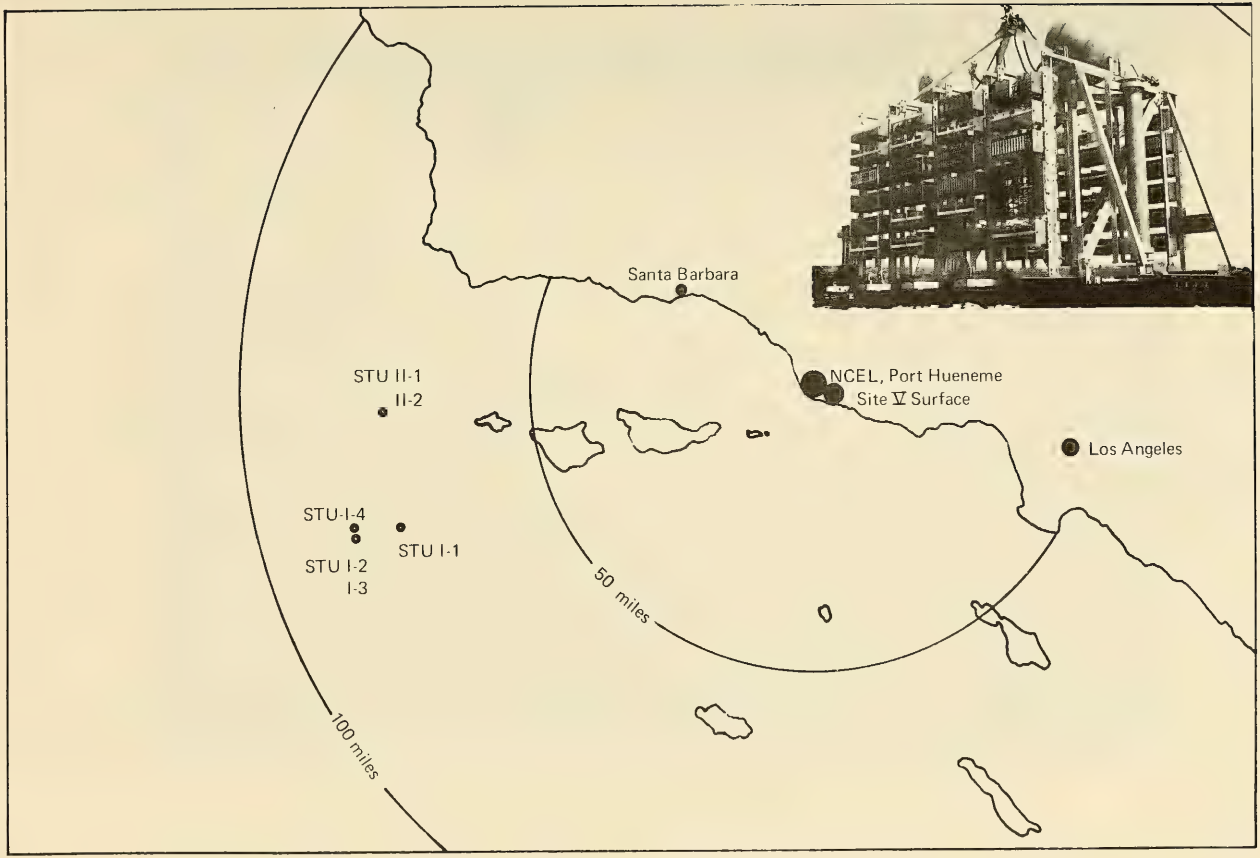

Figure 1. Geographical location of STU sites and STU structure.

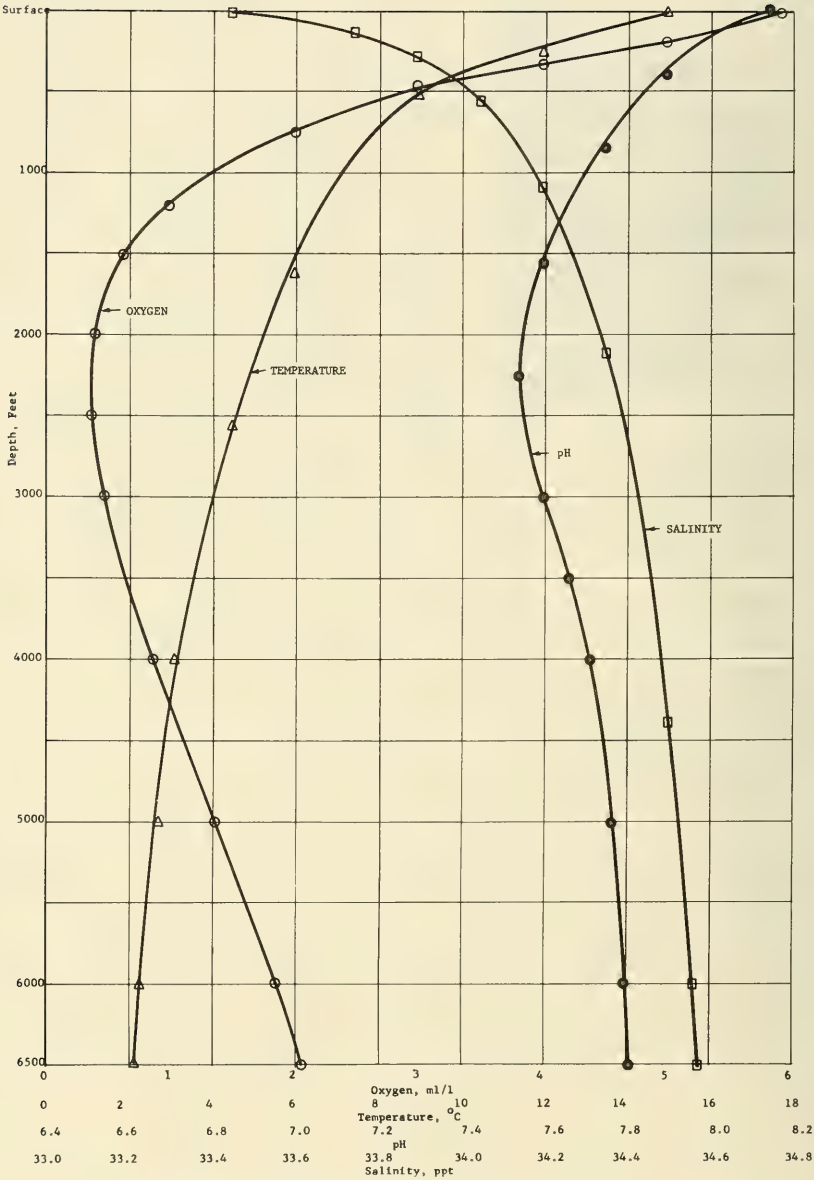

Figure 2. Oceanographic data at STU sites.

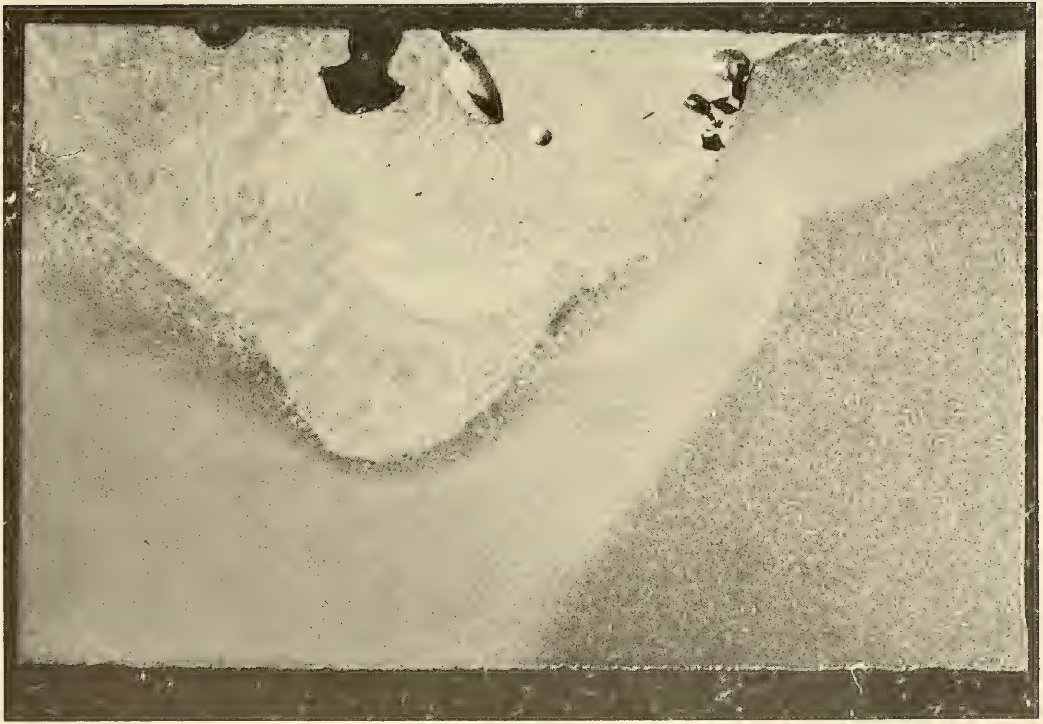

Figure 3. A transverse section through the pitted portion of the weld bead in HS #4 steel.

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13. ABSTRACT

A total of 525 specimens of 60 different alloys were exposed at a depth of 5,900 feet in the Pacific Ocean for 189 days in order to determine the effects of the deep ocean environments on their corrosion resistance.

Corrosion rates, types of corrosion, pit depths, and stress corrosion cracking resistance are presented.

The materials evaluated were aluminum alloys 5086-H34, H32 and H112 and 6061-T6, and welded and unwelded 5083-H113 and 7039-T64; welded nickel alloys Ni-Cu 400 and K-500, Ni-Cr-Fe 600 and 718, Ni-Cr-Mo 625, and Ni-Fe-Cr 825; and wire ropes Ni-Cr-Mo 625, Ni-Co-Cr-Mo, Ni-Mo-Cr "C" and Ni-Cr-Mo-103; three high strength-low alloy steels; six high strength steels; two austenitic cast irons; three stainless steels; two precipitation hardening stainless steels; and stainless steel and modified stainless steel wire ropes; and seven welded titanium alloys.

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Titanium alloys						
Wire rope						
Steels						
Stainless steels						
Cast iron						